CLARREO on JEM-ISS: Accommodation Feasibility

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Overview

- This study was initiated to determine the engineering feasibility of hosting the combined CLARREO MCR reflected solar and infrared instruments on the ISS.
- The "Kibo" - Japanese Experiment Module Exposed Facility (JEM-EF) site was specifically chosen due to field-of-regard (FOR), mass, power, and thermal management capabilities.
- This effort was a design study and not an "MCR-like" mission study with detailed ground operations, cost estimates, schedule, risk, or safety.

Questions to Answer

1. Could the instruments be packaged in an "ISS friendly" manner?
2. Could the ISS host the instruments in a "CLARREO friendly" manner?

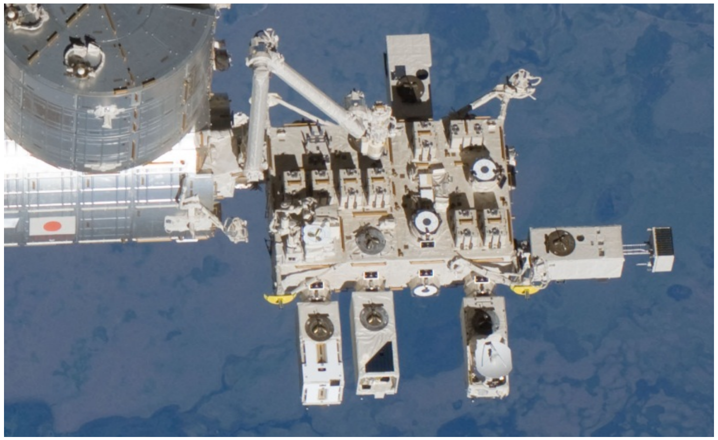
Scope of Accommodation Study

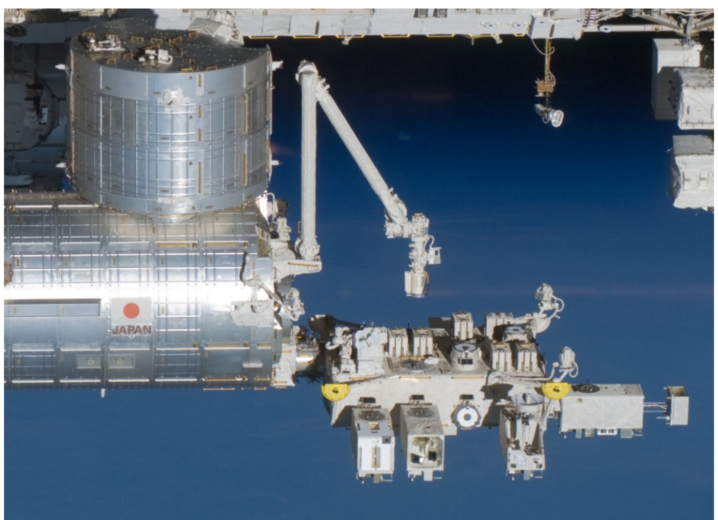
- Conceptually the instruments were “in storage” and would need only minimal modifications and the required ISS packaging and interfaces.
- No GNSS-RO (ruled out in earlier study)
- No thermal management design
- No optimization of mass or power
- No vibration or jitter analyses
- No ISS roll-pitch-yaw off-nominal considerations
- No contamination analysis

This effort represents our first design assessment of placing both CLARREO science instruments on the ISS

JEM-EF OVERVIEW

Kibo Module Has Both Pressurized and Exposed Facilities

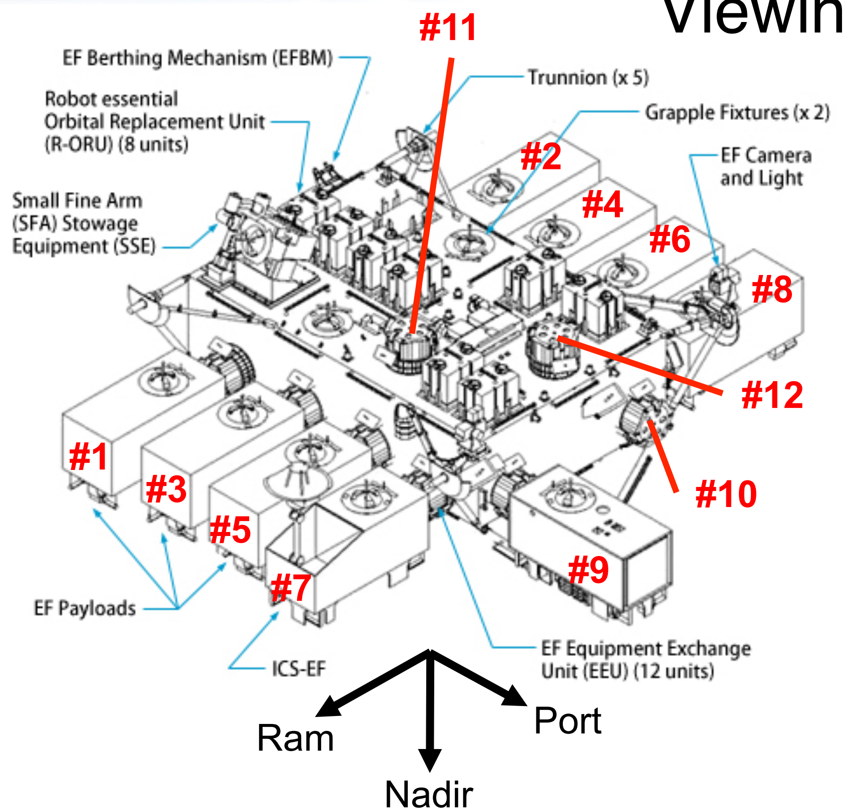




JEM Pressurized and Exposed Facilities

- JAXA provided facility
- Modules launched on STS-123, STS-124, and STS-127
- Independent communications capability via ICS

Exposed Sites Have Differing Mass, Power, Data, and Viewing Capabilities



Location	Viewing	Payload Size	Description / Notes	Power	Data
1	Ram, Nadir, Zenith	500 kg	Ram field of View (FOV) obstruction by JEM module	6 kW	Ethernet, 1553, Video
3	Ram, Nadir, Zenith	500 kg	Clear view	3 kW	Ethernet, 1553, Video
5	Ram, Nadir, Zenith	500 kg	ICS System back-up site (negotiable?)	3 kW	Ethernet, 1553, Video
7	Ram, Nadir, Zenith	500 kg	ICS-dedicated	-	-
9	Port, Zenith, Nadir	2.5 MT	Best volumetrically for large payloads (up to 2.5 MT), but not necessarily the best viewing	3 kW	Ethernet, 1553, Video
2	Wake, Nadir, Zenith	2.5 MT	Can hold large payloads, but has an FOV obstruction by JEM module	6 kW	Ethernet, 1553, Video
4	Wake, Nadir, Zenith	500 kg	Clear view	3 kW	1553, Video
6	Wake, Nadir, Zenith	500 kg	Clear view	3 kW	Ethernet, 1553, Video
8	Wake, Nadir, Zenith	500 kg	Obstruction during EP berthing, slight obstruction from camera mount	3 kW	1553, Video
10	Wake, Nadir, Zenith	500 kg	EPMP berthing site	-	-
11	Zenith only	500 kg	Good Zenith viewing	3 kW	Ethernet
12	Zenith only	500 kg	Temporary stowage location	3 kW	Ethernet

Earth Venture 2 Workshop

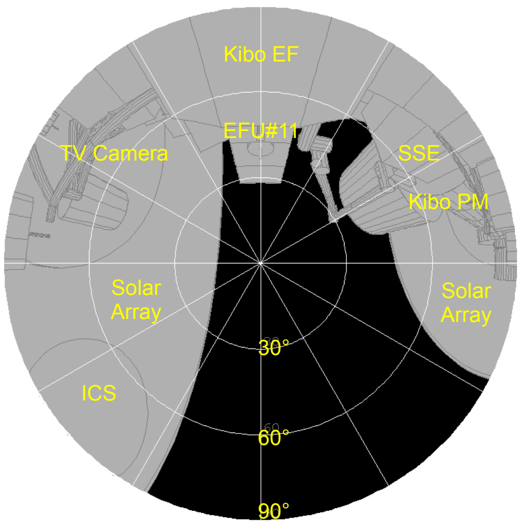
- EFU#5 chosen as best candidate with EFU#3 and #1 as backups
- EFU#2, #4, #6, and #8 are candidates for an IR-only configuration due to truss structures, radiators, and several connecting modules

CLARREO-ISS Accommodation Compliance Matrix

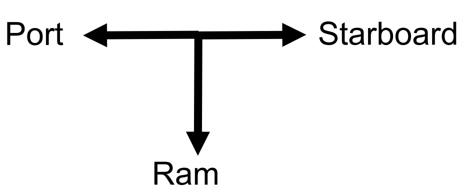
	JEM-EF	CLARREO-ISS
Mass	550 kg (standard site)	~453 kg with GFE (~20% margin)
Power	3 kW (standard site)	~250 W (~92% margin)
Thermal	3 kW (fluid cooling loop)	~250 W
Data Rate	1 Mbps (MIL-STD-1553) 10 Mbps (10 Base-T Ethernet) 43 Mbps (Shared-Negotiated) NTSC Video	~640 kbps to ~72 Mbps (Highest rate due to RS during solar calibration requires data buffering at the payload)
Data Volume	Negotiable – Up to 1.5 TB	~90 Gb/day
Volume	0.8 x 1.0 x 1.85 m	Complies (stowed)

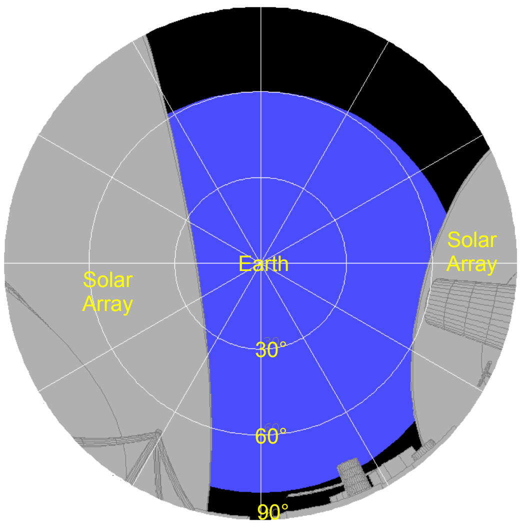
Field-of-Regard Varies Due to Solar Array, ISS Attitude, and ICS Motion

Kibo Exposed Facility User Handbook, September 2010

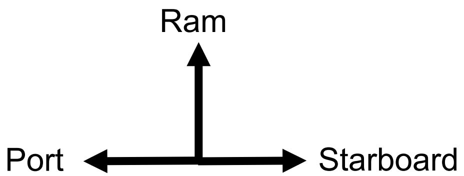


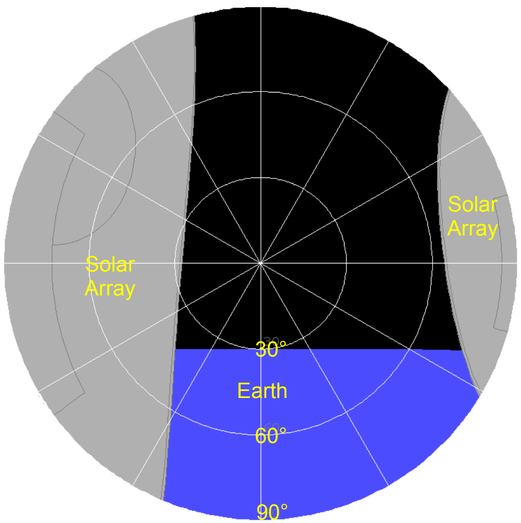
Viewing Point: Center of zenith face of EFU#5
Viewing Direction: Zenith



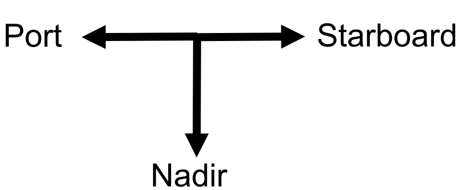


Viewing Point: Center of nadir face of EFU#5
Viewing Direction: Nadir



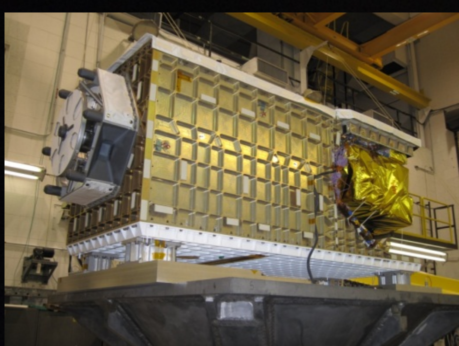


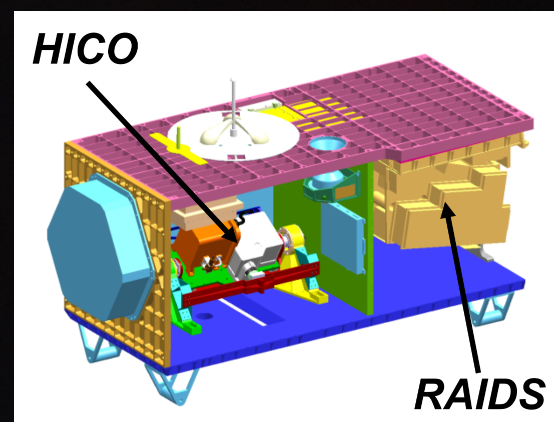
Viewing Point: Center of ram face of EFU#5
Viewing Direction: Ram (Velocity)



- Pitch offset from nadir predicted to be -10 to +2 degrees after ISS completion

Dual Manifest Payload on JEM-EF Demonstrated by HREP





- Led by NRL, HREP deployed on JEM-EF October 2009.
- HREP was the first US science payload utilizing JEM-EF.
- Partnerships between NASA, NRL, DOD Space Test Program, and ONR.

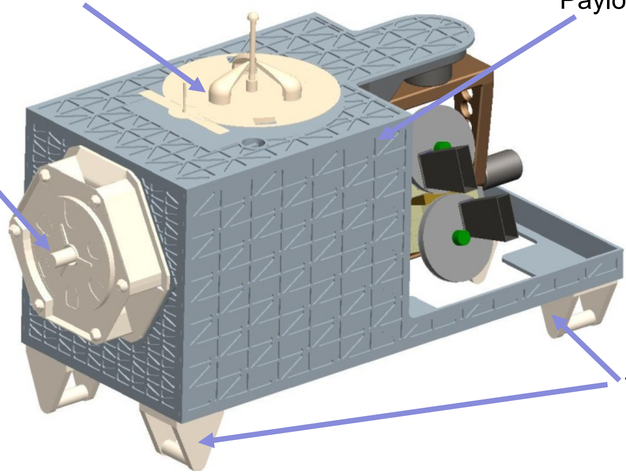
SS020E041981

CLARREO-ISS OVERVIEW

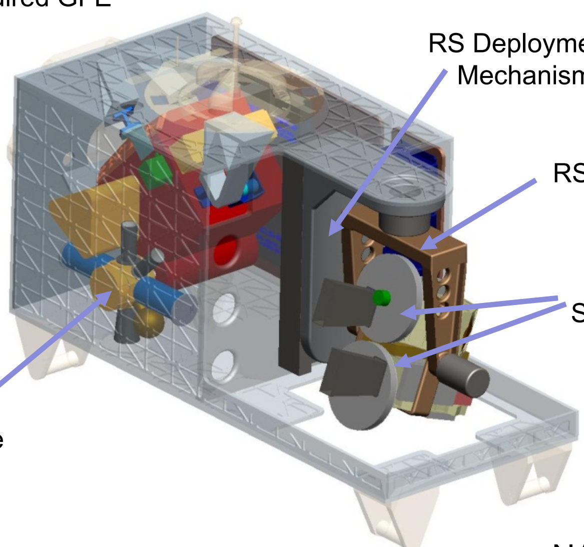
Lessons Learned from Combined Observatory Free-Flyer Spacecraft Studies

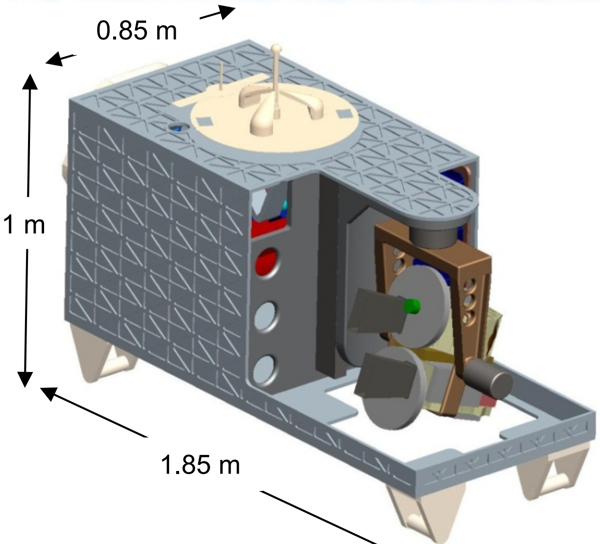
- The Reflected Solar wanted to be on the ram/wake end to have the best views for solar calibration-lunar verification.
- The Reflected Solar also wanted nadir views with large off-nadir view angles for reference intercalibration.
- The Reflected Solar needed a two-axis gimbal for pointing agility and to avoid loss of IR data.
- The IR could be closer to the bus and still have unobstructed nadir, zenith, and off-zenith views for benchmarking, a cold reference, and periodic polarization checks.
- The overall configuration worked best when radiators were placed on the spacecraft “cold” side for thermal maintenance.

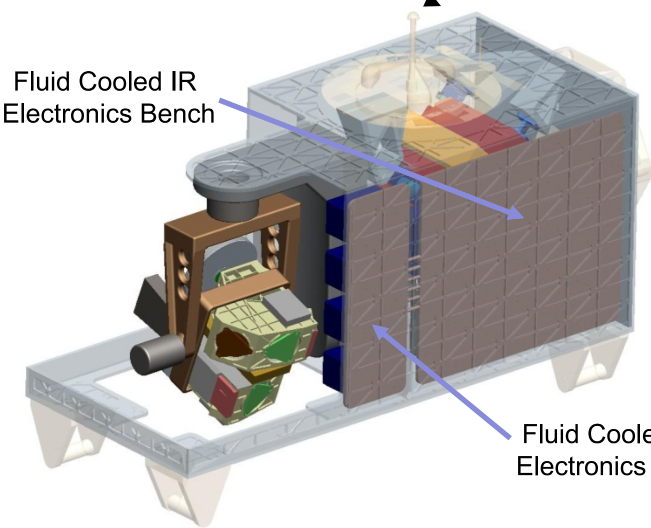
CLARREO-ISS Payload Concept Compatible with JEM-EF



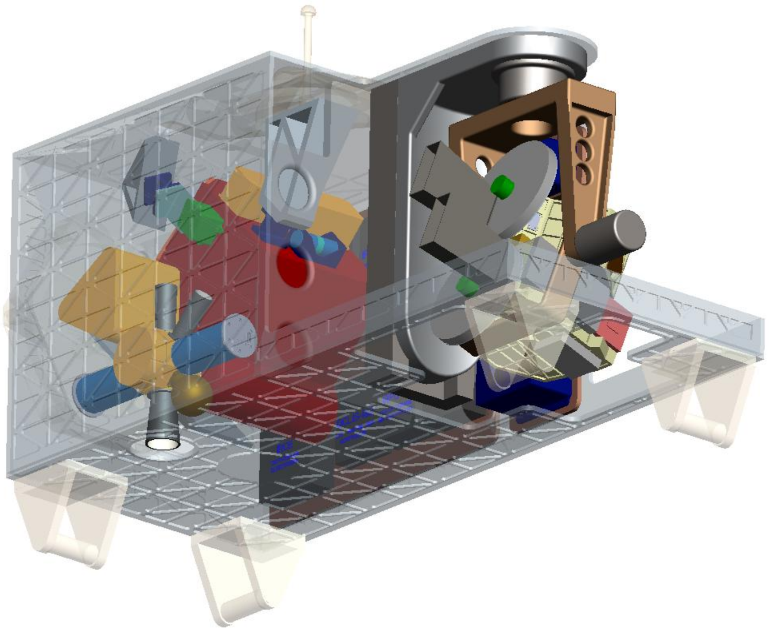
* = Required GFE

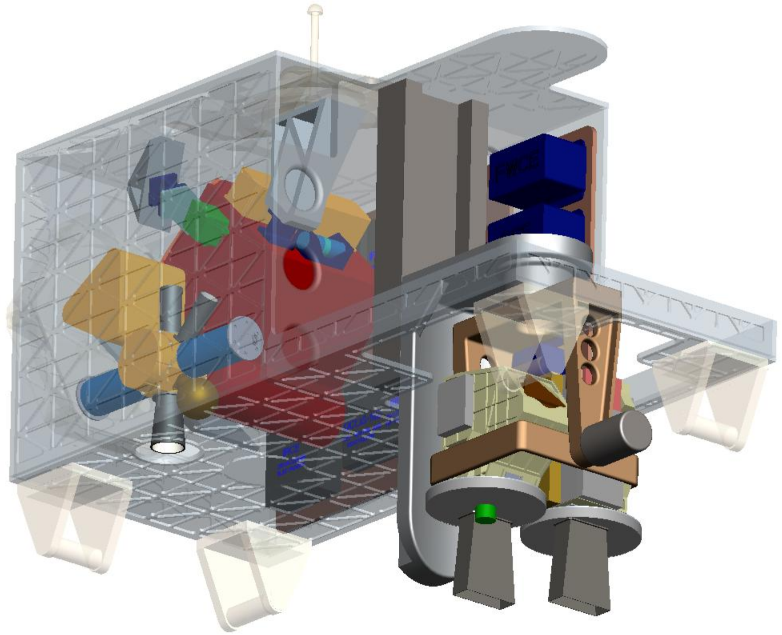






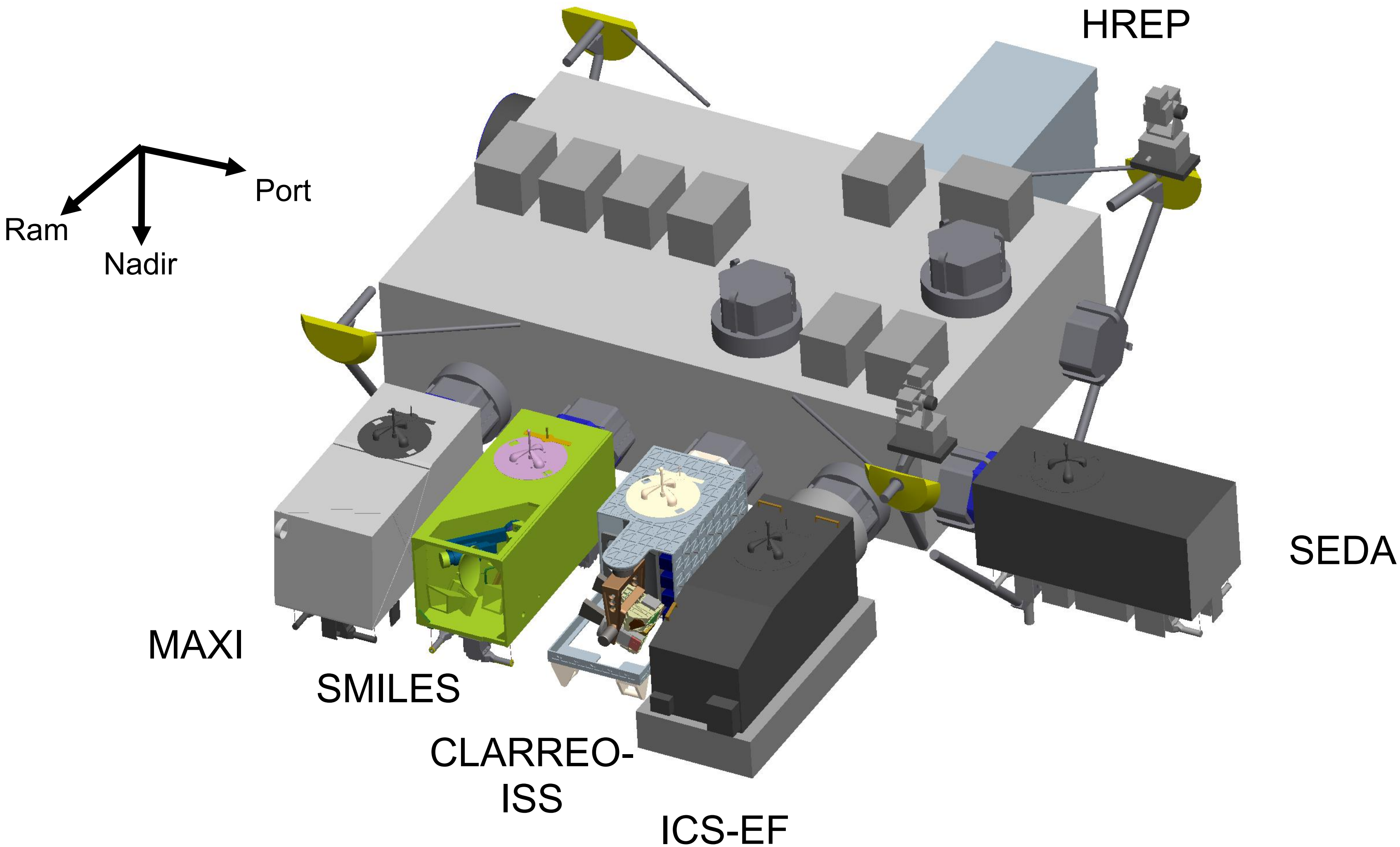
JEM-EF Allows for Deployable Payloads in the Nadir Direction





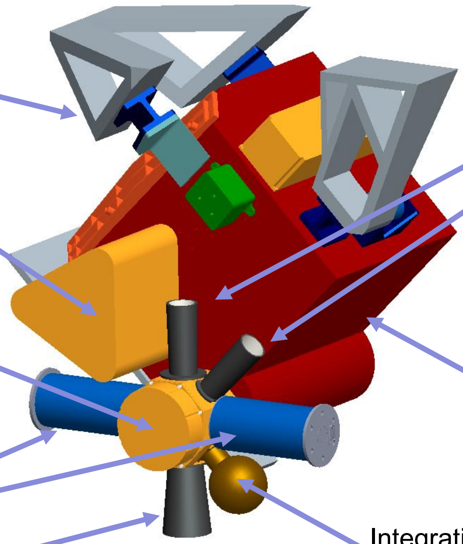
Due to constraints on maintaining the field-of-view of neighboring ICS payload’s Earth and Sun sensors, the RS cannot deploy through the end (ram deck) but can deploy through the bottom (nadir deck).

CLARREO-ISS on JEM-EF Configuration



IR SUITE

Modified IR Suite Overview



JEM-EF IR Instrument Concept Design
(Rotated 45°from MCR Concept)

Baseline Instrument Package:

- *FTS, calibration-verification system, thermal management hardware, support structure, and electronics*
  - Mass: ~74.8 kg (59.8 kg + 15 kg electronics)
  - Power: ~124 W
- *Instrument Dimension: ~0.8m x 0.76m x 0.58m*
- *Data Rate: ~228 kb/sec*
- *Data Volume: ~20 Gb/day*

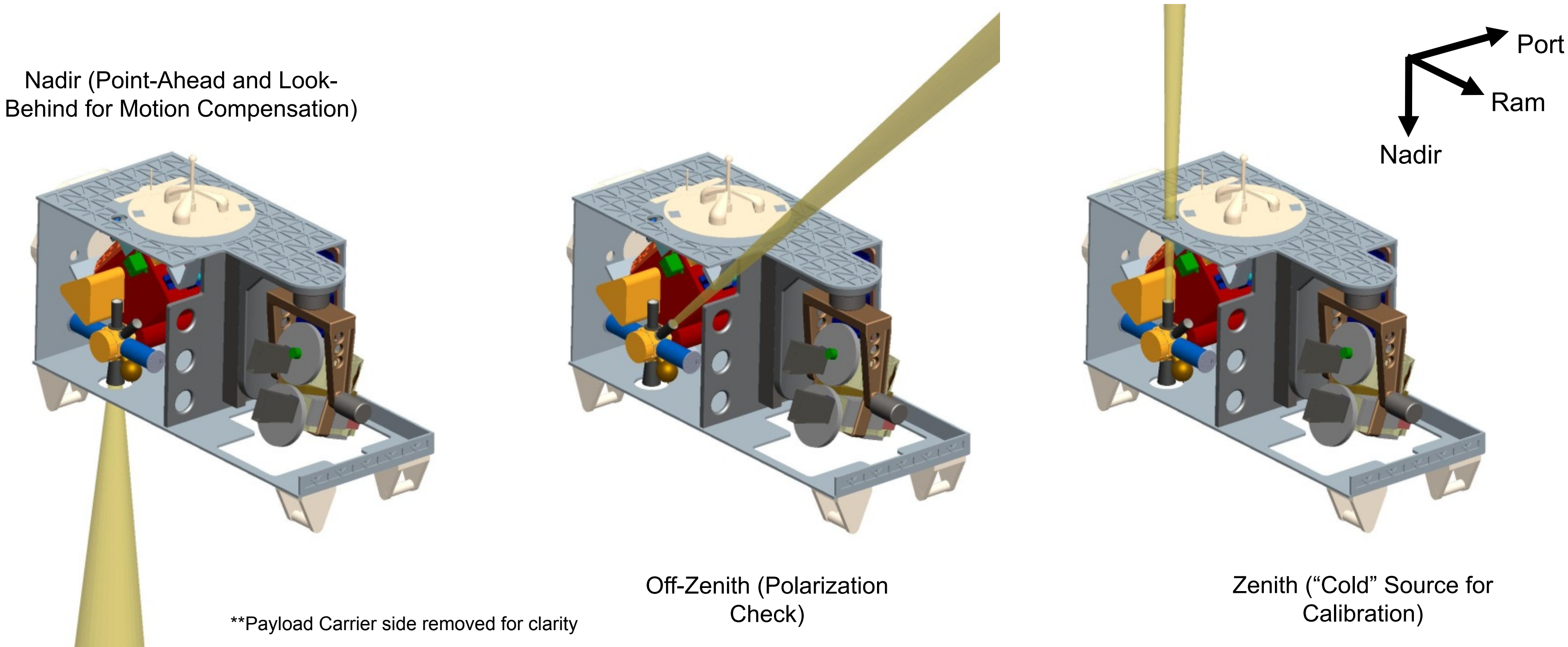
Instrument Description:

- *A Fourier Transform Spectrometer (FTS) for SI traceable measurements of the Mid and Far-IR spectrum of the Earth and atmosphere*
- *Utilizes one ambient black body, one phase-change black body, and deep space as on-orbit calibration sources*
- *Scene select mechanism utilized for ISS motion compensation and calibration source selection*
- *Uncooled pyroelectric detector for the Far-IR*
- *Two-actively cryocooled HgCdTe (MCT) detectors for the Mid-IR*

Characteristics:

- *Radiance Scale Accuracy: 0.1 K 3σ*
- *Spectral Range:*
  - ~ 5-50 μm (200-2000 cm^{-1})
- *Unapodized Resolution: 0.5 cm^{-1}*
- *Detectors:*
  - MCT #1: ~3 to 9 μm (1111-3333 cm^{-1})
  - MCT #2: ~8 to 16.5 μm (606-1250 cm^{-1})
  - Pyroelectric: ~15 to 50 μm (200-667 cm^{-1})
- *Footprint: ~17 km from 400 km*
- *Integration Period: ~ 8 seconds*

IR Operational Concept Very Similar to Free-Flyer



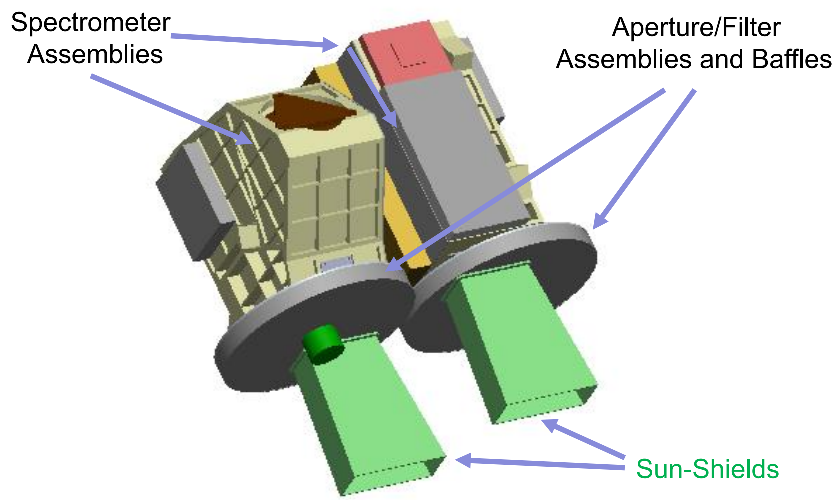
- JEM-EF provides unobstructed views for nadir, zenith, and off-zenith collections.
- ISS pitch offset (port rotation) from nadir implies an offset of ~4° in the IR mounting interface or in the scene-select mirror zero position.
- ISS roll-yaw offsets need error contribution evaluation for CLARREO.
- An IR-only payload could also function on the opposite (wake) side of JEM-EF.

REFLECTED SOLAR SUITE

Climate Absolute Radiance & Refractivity Observatory

CLARREO

Modified Reflected Solar Suite Overview



JEM-EF Reflected Solar Suite Design Concept

(One spectrometer rotated about boresight from MCR Concept)

Baseline Instrument Package:

- *Two spectrometers and aperture-filter wheel assemblies*
  - Mass: ~53.2 kg (33.7 kg + 19.5 kg electronics)
  - Average Power: ~96 W
- *Dimension: ~0.58m x 0.56m x 0.32m*
- *Data Rate:* (with 2x compression)
  - Solar Calibration: ~72 Mb/sec
  - Nadir Collection: <0.5 Mb/sec
- *Data Volume:* (with 2x compression)
  - Typical: ~66 Gb/day
  - Peak: ~69 Gb/day

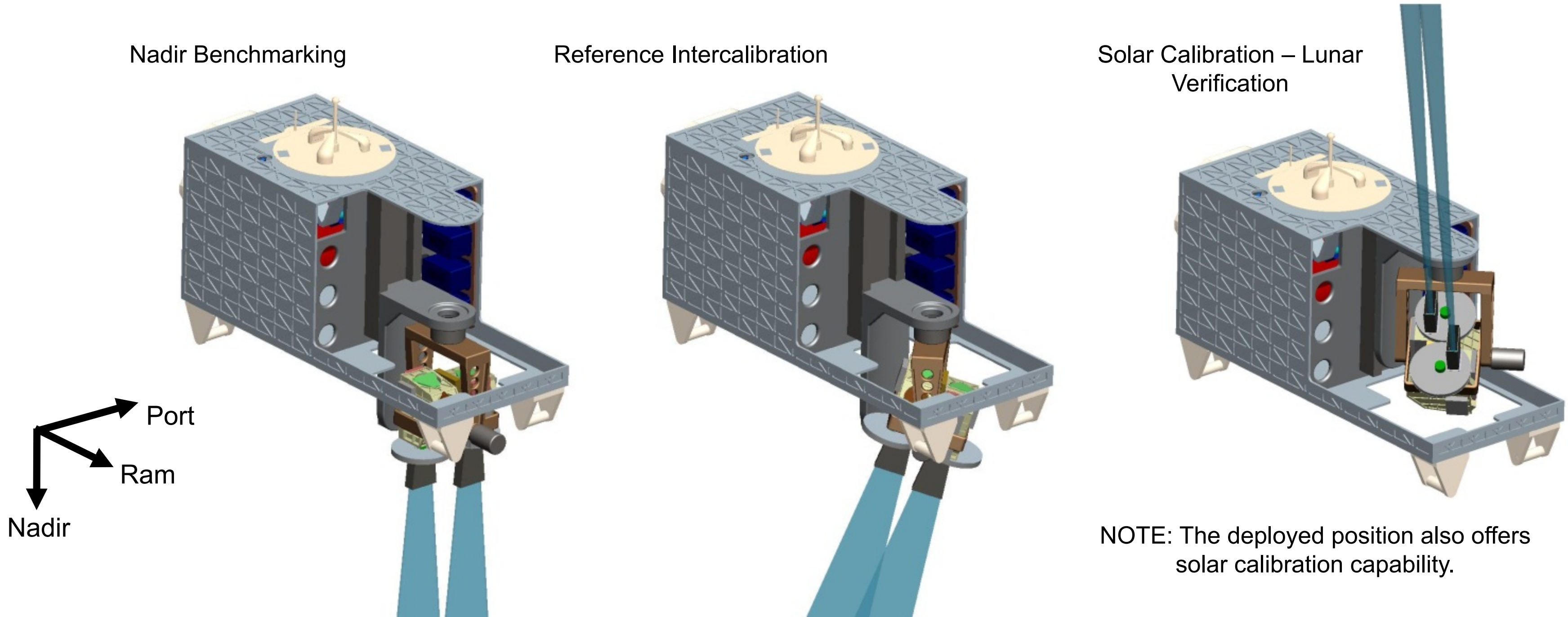
Instrument Description:

- *A pair of pushbroom hyperspectral imagers with high spatial and spectral resolution*
- *Measures solar spectral reflectance of the Earth and its atmosphere relative to the solar irradiance spectrum*
- *On-orbit calibration using the sun and moon as sources obtained through precision apertures, neutral density filters, and perforated plates rotated via filter wheels*
- *Field of regard (FOR) for reference intercalibration, solar calibration, and lunar calibration verification achieved with two-axis gimbal and deployment mechanism*

Characteristics:

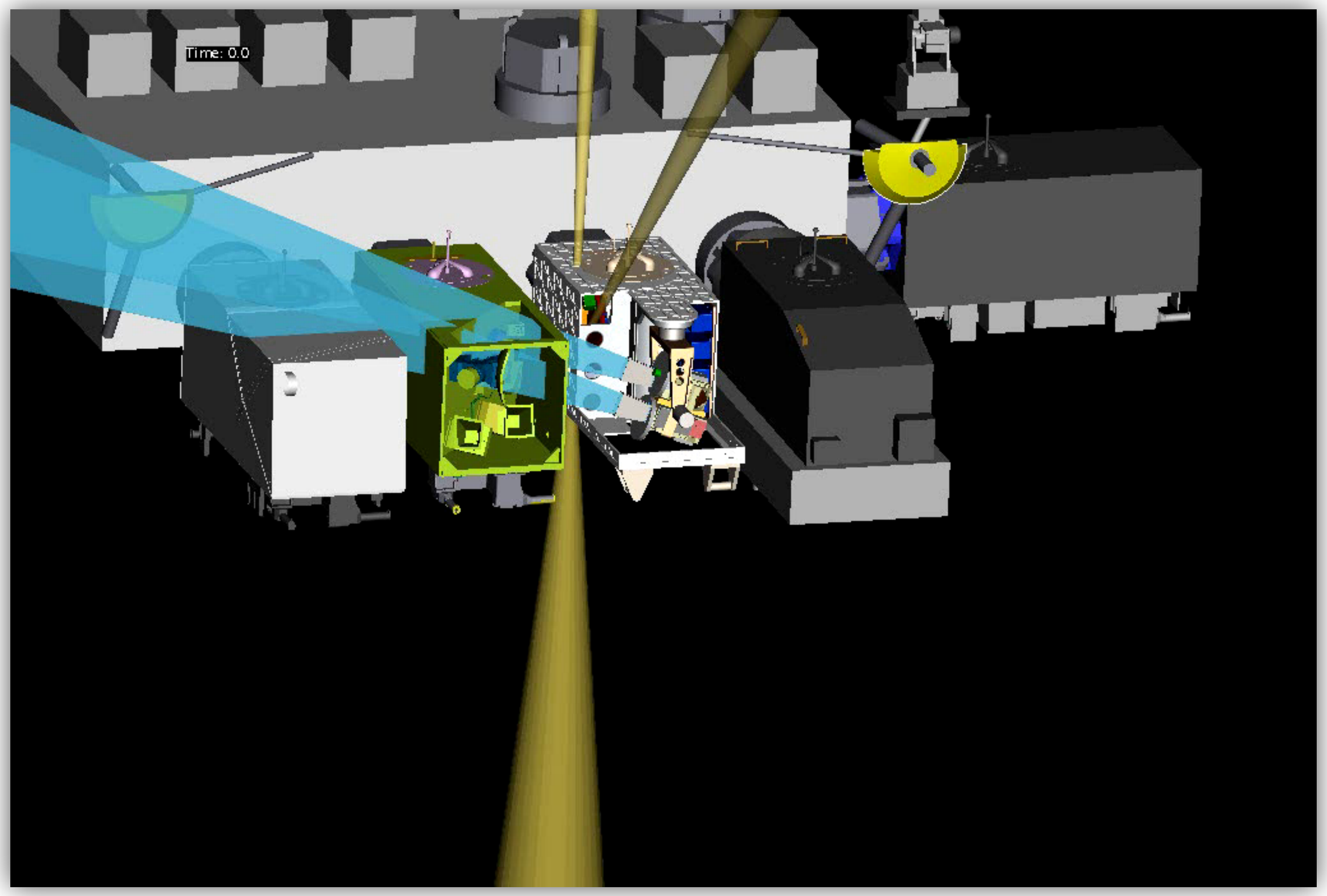
- *Absolute reflectance measurement uncertainty of 0.3% at 2σ confidence for the total integrated broadband reflected solar spectrum*
- *Polarization sensitivity <0.25% below 1000 nm and <0.75% at other wavelengths*
- *Spectral Range: 320 – 2300 nm*
  - ~320 to ~640 nm ("Blue")
  - ~600 to ~2300 nm ("Red-NIR")
- *Spectral Sampling: ~2 – 4 nm*
- *Swath Width: > 67 km cross-track from 400 km*
- *Spatial Sampling : ~0.34 km at Nadir*

RS Operational Concept Very Similar to Free-Flyer

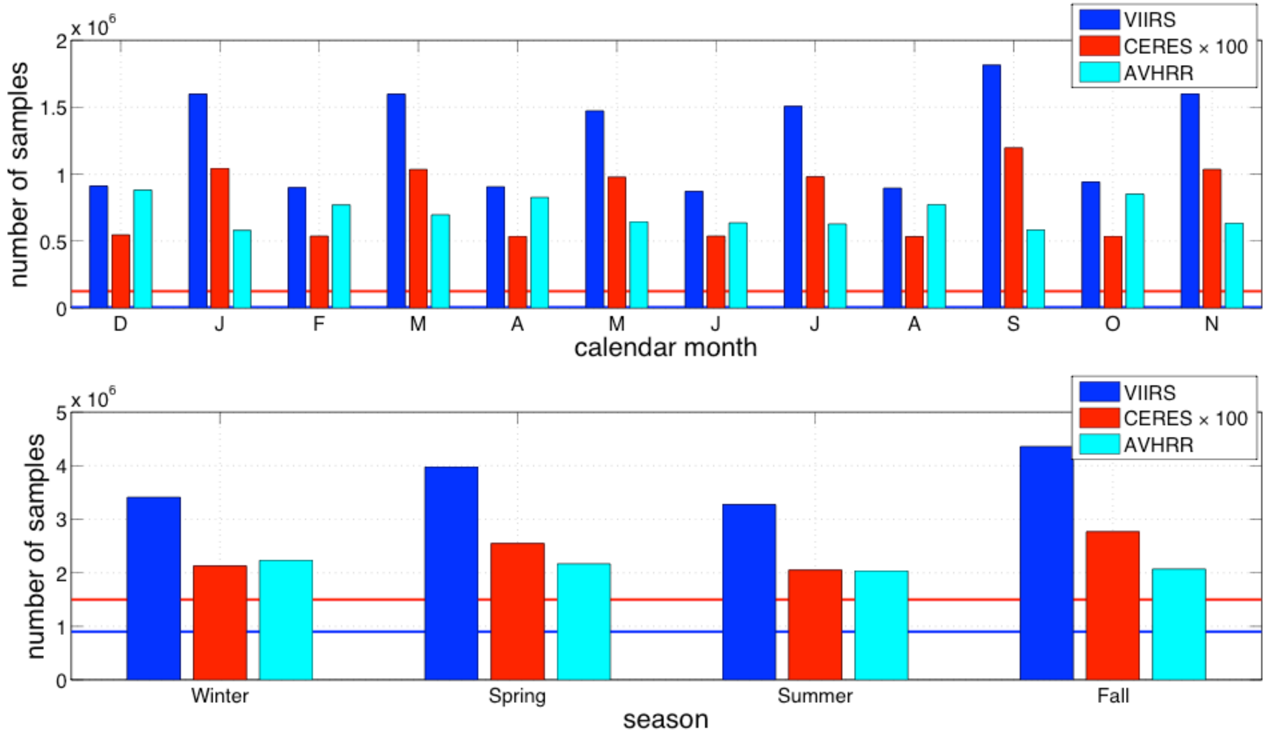


- JEM-EF provides predominantly unobstructed views for benchmarking and reference intercalibration with a deployable gimbal-instrument.
- Views are more constrictive for solar calibration and lunar verification due to neighboring payloads. (Results in later slide)
- Calibration-verification could be more complex than free-flyer due to timing with solar array positions and ISS roll-pitch-yaw offsets.
- IR+RS or RS-only payload probably not viable on the opposite (wake) side of JEM-EF due to additional ISS structure interfering with calibration-verification.

RS Benchmarking-Intercalibration Ops Concept



RS Reference Intercalibration Opportunities Study Overview

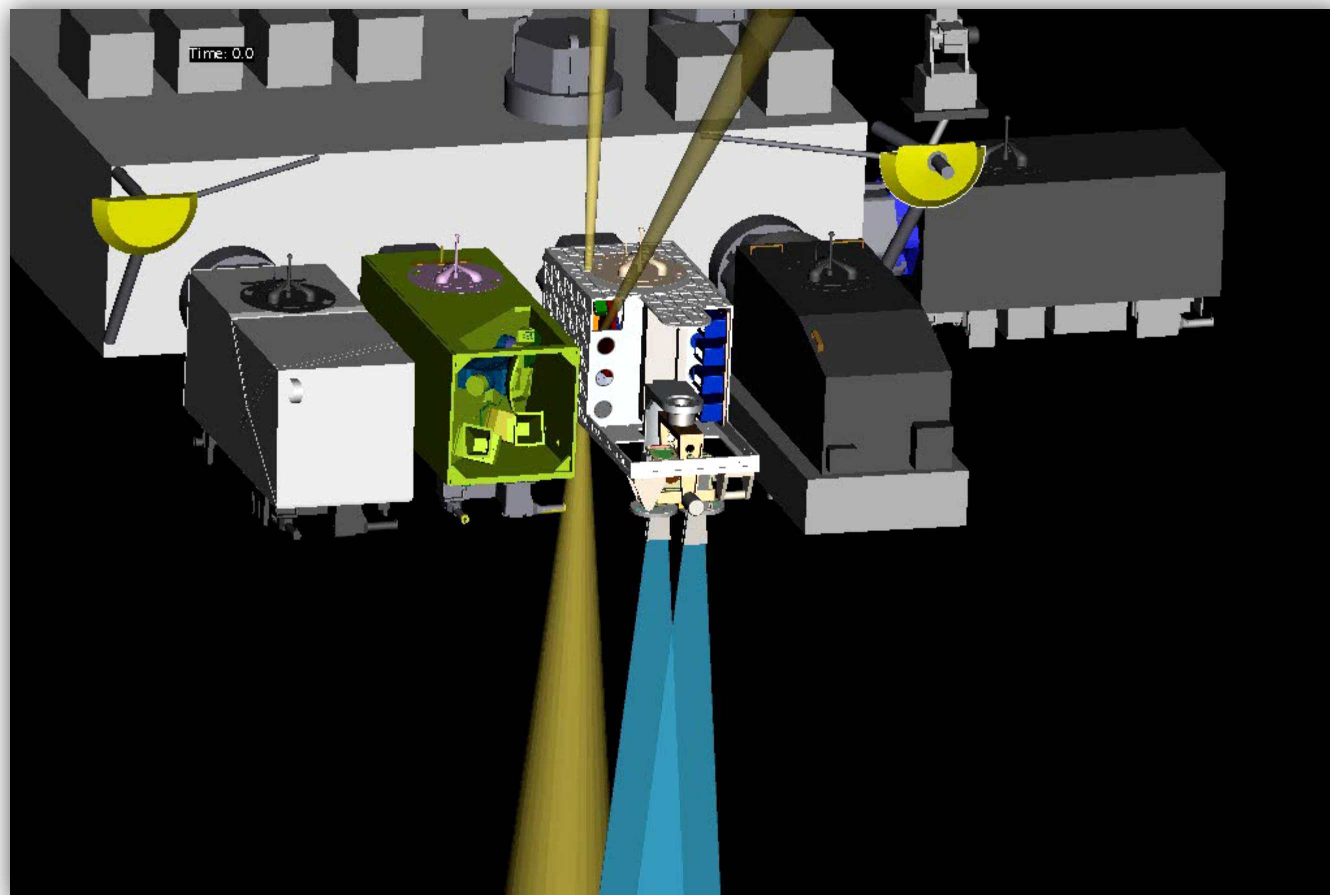


Monthly and Seasonal Sampling Estimates, ISS vs: JPSS-VIIRS, JPSS-CERES, and MetOp-AVHRR

1st Annual International Space Station Research and Development Conference, June 26 – 28, 2012, Denver, Colorado

NASA Langley Research Center

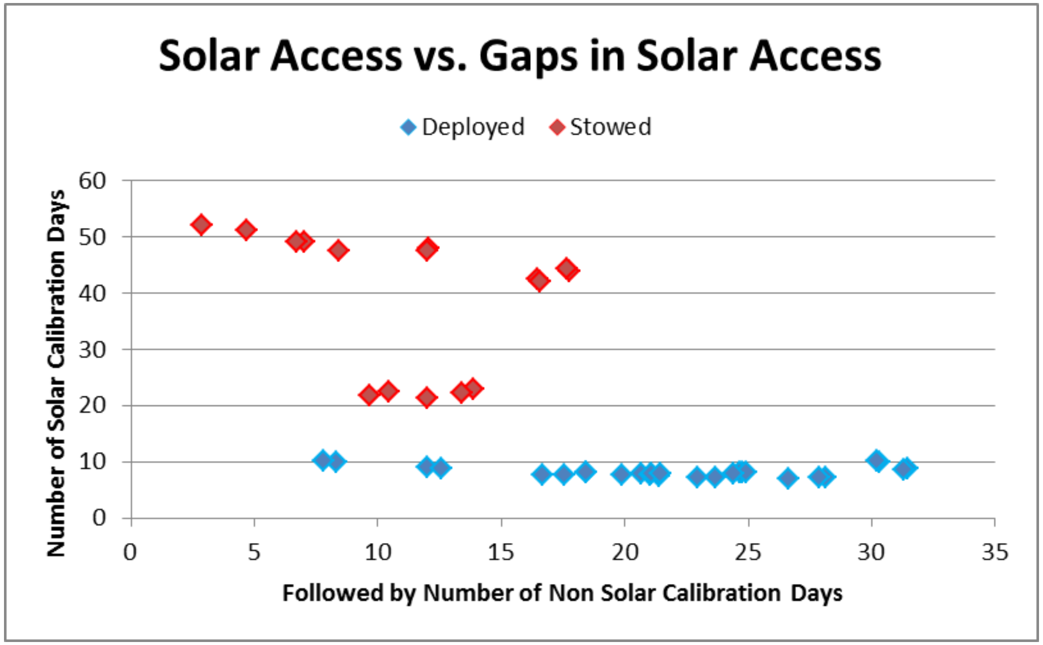
RS Solar Calibration-Lunar Verification Ops Concept



Solar Calibration Overview

Solar Calibration opportunities are regularly available in both the undeployed and deployed configurations.

- From the undeployed configuration, solar calibration opportunities span 21-52 days which are followed by 3-20 day gaps.
- From the deployed configuration, solar calibration opportunities span 7-32 days followed by 7-11 day gaps.
- The undeployed configuration would enable greater scheduling flexibility for calibration while remaining in the desired configuration for benchmark and reference intercalibration measurements.



Solar Calibration Cycle Summary	Gap Duration (days)	Prior Access Duration (days)	Ind. Accesses	Cumulative Solar Access Time per Cycle (m)
Deployed Averages	21.8	8.2	135.0	599.3
Undeployed Averages	11.4	37.1	610.0	3775.7

Lunar Verification – Operational Constraints Same as Free-Flyer

- Lunar Verification Operations
  - Limited to occur while ISS is in umbra.
- *Earth Grazing Angle,* i.e. Earth limb to Moon angle as viewed by RS
  - Greater than 2.5 degrees
- *Lunation*, i.e. Sun-Moon-RS phase angle
  - Constrained from 5 to 9 degrees

- Lunar verification operations are only achievable while the RS instrument is in the undeployed configuration, i.e. the deployed field-of-regard prohibits lunar verification.
- The lunation constraint is not always met, i.e. some months do not meet viewing constraints. (See next page)

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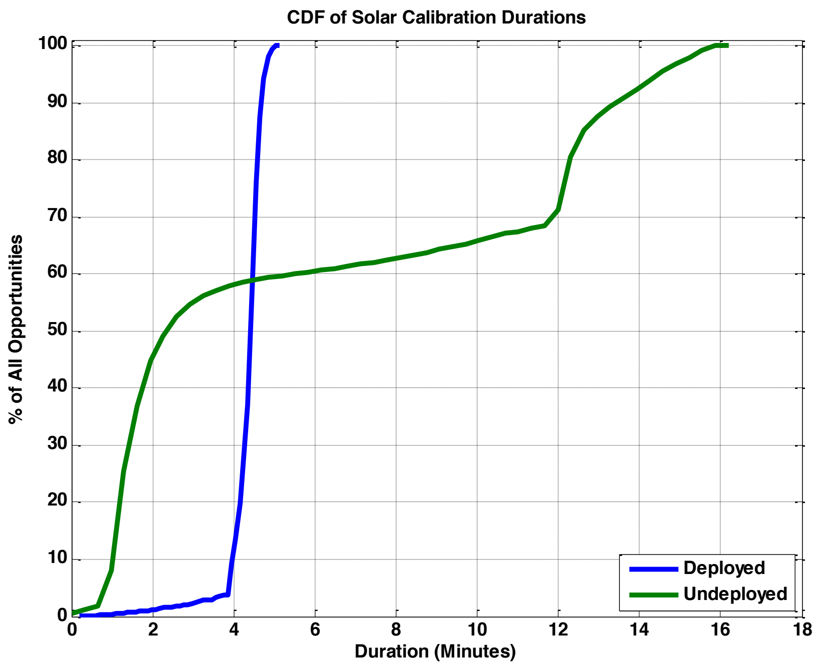
CLARREO

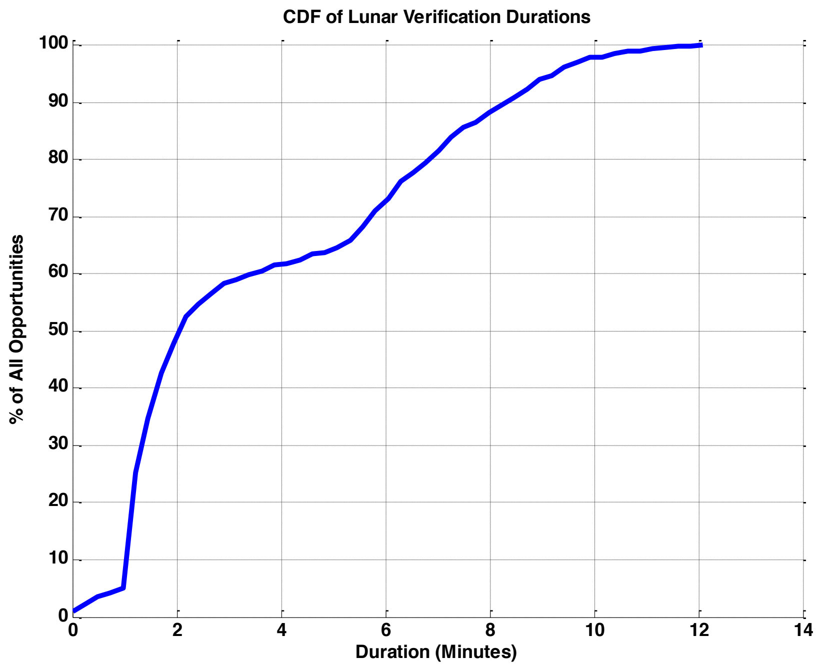
Lunar Verification – Study Results

- 2 year simulation was performed (Jan 2012 – April 2014).
  - Ephemeris estimates beyond 2014 quickly become inaccurate.
- The "Opportunities" column contains the number of times when the Moon can be viewed in the undeployed configuration.
- The "Mean Duration" column contains the average duration of all the viewing opportunities over each lunation.
- The "Cumulative" column contains the sum of all opportunities over each lunation.
  - There are instances in a given orbit when the Moon exits one viewing opportunity and enters the next after several seconds have elapsed.

Lunation	Start Date	Opportunities (#)	Mean Duration (minutes)	Cumulative (minutes)
1	7-Feb-12	28	6.4	178.6
2	8-Mar-12	0	0.0	0.0
3	5-Apr-12	0	0.0	0.0
4	5-May-12	19	2.0	38.8
5	3-Jun-12	0	0.0	0.0
6	3-Jul-12	22	1.7	36.7
7	1-Aug-12	2	0.3	0.7
8	30-Aug-12	28	3.4	94.4
9	29-Sep-12	42	4.2	178.1
10	29-Oct-12	11	2.5	27.4
11	27-Nov-12	24	4.5	107.9
12	27-Dec-12	10	4.8	47.5
13	26-Jan-13	39	3.5	136.9
14	25-Feb-13	27	3.0	79.9
15	26-Mar-13	29	4.7	136.9
16	25-Apr-13	18	4.5	80.3
17	24-May-13	20	5.9	118.4
18	22-Jun-13	20	3.9	77.3
19	22-Jul-13	40	4.7	187.4
20	20-Aug-13	25	3.6	89.2
21	18-Sep-13	24	4.6	109.5
22	18-Oct-13	20	3.6	71.2
23	16-Nov-13	22	4.1	89.6
24	16-Dec-13	36	2.9	105.9
25	15-Jan-14	32	3.9	123.5
26	14-Feb-14	43	3.5	149.7
27	15-Mar-14	25	4.3	106.8
28	14-Apr-14	24	4.1	98.2
AVERAGES		**22.5**	**3.4**	**88.2**

Solar Calibration-Lunar Verification Cumulative Data Functions





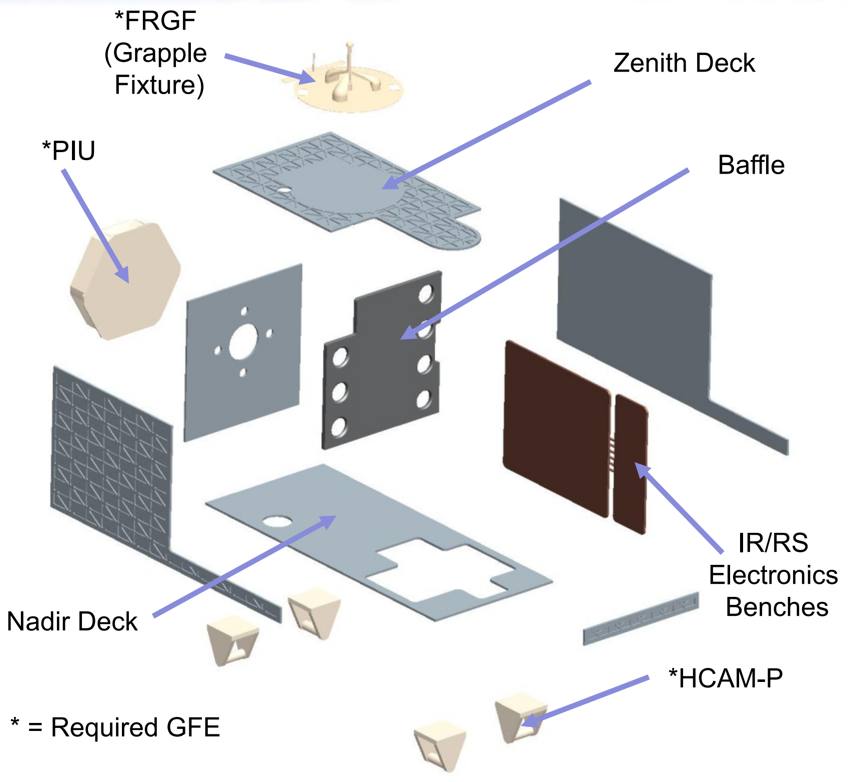
Conclusions

- At a high-level the concept of utilizing the JEM-EF for CLARREO-ISS appears feasible.
- The CLARREO-ISS concept is “ISS friendly”.
  - Design drivers of mass, power, volume, and thermal all seen as a reasonable design space.
  - HREP dual-payload success adds credibility to the concept.
- The JEM-EF is “CLARREO friendly” but perhaps not ideal for a combined IR+RS payload.
  - The IR configuration appears closer to a dedicated free-flyer than the Reflected Solar.
  - Reflected solar calibration and lunar verification opportunities should be assessed by the Science Team.

Questions?

BACKUPS

Payload Carrier Overview



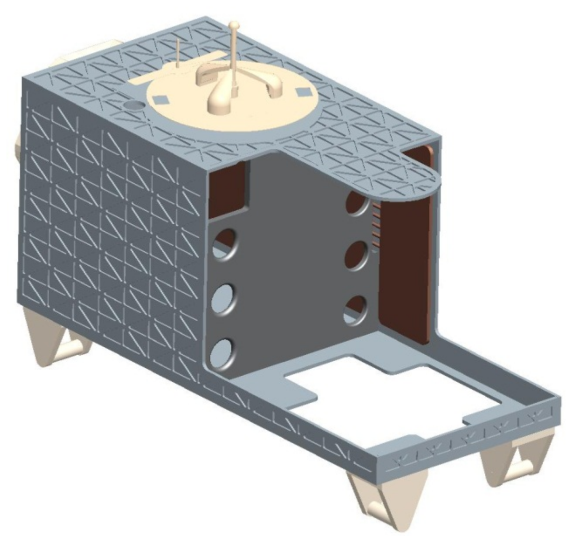
Payload Carrier Concept

Baseline :

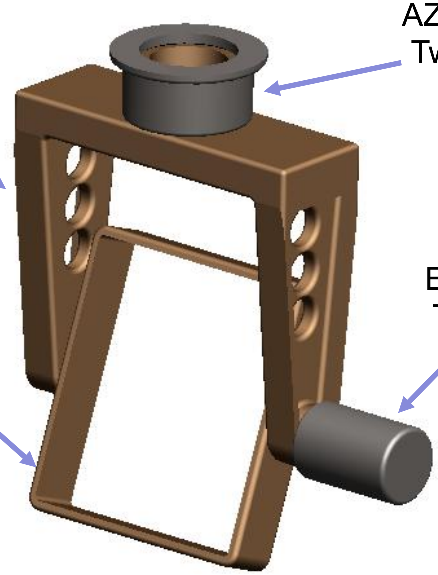
- *All required GFE, support structure, and IR-RS Electronics Benches*
  - Mass: ~236 kg (149 kg + 27 kg electronics benches + 60 kg GFE)
- *Dimension: ~0.8m x 1m x 1.85m*

Description:

- *Simple aluminum structure provides instrument and required GFE mounting interfaces*
- *Viewports for IR nadir, zenith, and off-zenith views*
- *Structural provisions for RS field of regard to enable calibration-verification, nadir benchmarking, and reference intercalibration*
- *Fluid cooling capability of JEM-EF utilized in IR and RS Electronics Benches*
- *Meets JEM-EF guidelines for volume and deployment envelope to avoid interference with other payloads and EVA compliance*



Two-Axis Gimbal Overview



Two-Axis Gimbal Concept Design
(Electronics and Cabling not Shown)

Baseline Concept:

- *Gimbal , electronics, and cabling*
  - Mass: ~25 kg
  - Average Power: ~21 W
  - Peak Power: ~92 W
- *Dimension: ~0.5m x 0.6m x 0.37m*
- *Data Rate: ~10 kb/sec*
- *Data Volume: ~300 Mb/day*

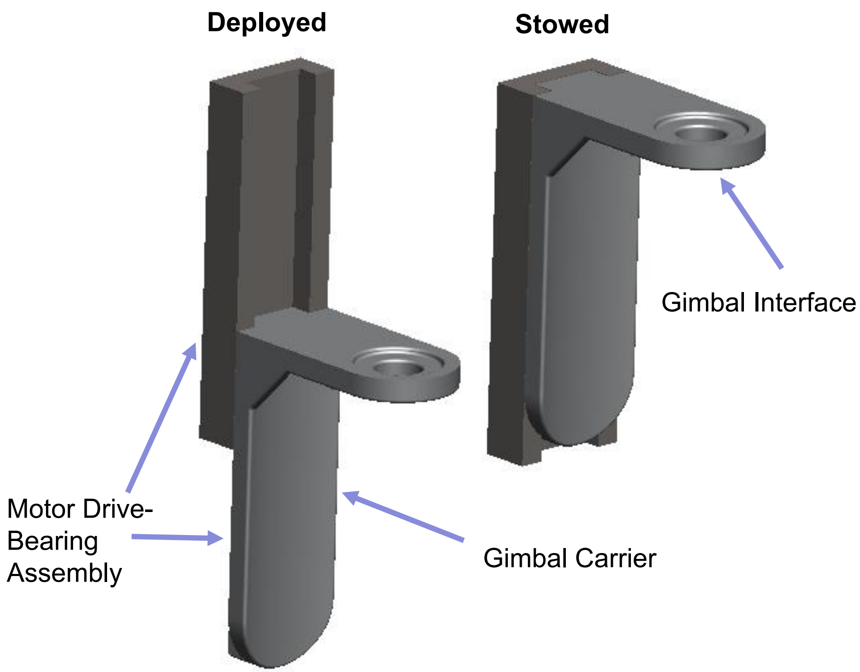
Description:

- *Two-Axis gimbal supports benchmarking, reference intercalibration, solar calibration, and lunar calibration verification modes of operation*
- *Allows independent pointing and tracking with respect to the ISS*
- *High-TRL components and similar gimbals have flight heritage*
- *DC brushless motors using resolvers or encoders for closed-loop control and motor commutation*
- *Twist capsules or cable wrap used to carry gimbal and reflected solar signals and power across rotating interfaces*

Characteristics:

- *AZ Range: +/- 180 degrees*
- *EL Range: +/-140 degrees (with spectrometers)*
- *Slew Rates: < 5 deg/sec (both axes)*
- *Tracking Rates: <1.5 deg/sec*
- *Acceleration: < 1 deg/sec^2 (both axes)*

Deployment Mechanism Overview



Deployment Mechanism Design Concept

Baseline Concept:

- *Mechanism, drive, electronics, and cabling*
  - Mass: ~64 kg (TBR)
  - Peak Power: ~10 W (TBR)
- *Dimension:*
  - *Stowed: ~0.25m x 0.58m x 0.75m*
  - *Deployed: ~0.25m x 0.58m x 1.23m*

Description:

- *Simple linear translation stage provides stowage/ deployment capability for the RS gimbal and spectrometer assemblies*
- *Supports RS gimbal and spectrometer assemblies within the payload carrier for launch, docking, and JEM-EF installation*
- *Deploys RS gimbal and spectrometer assembly through the payload carrier nadir deck to allow off-nadir pointing required for the RS operational modes*
- *High-TRL components and similar mechanisms have flight heritage – bearings, motor, ball screw*
- *Limit switches provide verification of home-deployment positions*
- *Mechanism with no precision position or rate and low life-cycle requirements*

Characteristics:

- *Range of Motion: 0 to 0.5 m*
- *Position Knowledge: < 1 mm (TBR)*
- *Position Control: < 0.5 mm (TBR)*

JEM-EF Provides Accommodation Approaching a Free-Flyer for the IR